INDUSTRIAL GAS TURBINE FUEL SURVEY-BASIC PROPERTIES

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ABSTRACT

In the last few decades, the quality of industrial feedstocks to refineries has continued to decline. Here in the United States many of the large remaining petroleum reserves are high in aromatics and sulfur content, while at the same time environmental standards call for lower sulfur in all fuel classes, and reduced aromatics in the large volumes of gasoline produced. These competing requirements force refineries to upgrade the feedstocks more aggressively in order to comply with the stricter environmental standards. This is particularly true of feedstocks coming from the west coast, or the Alaskan North Slopes. The impact of these lower quality feedstocks is expected to impact the quality of the final products available.

To ascertain the general quality of industrial fuels used in gas turbines, a survey of liquid fuels was undertaken. The purpose of the fuel survey was to characterize the properties of both domestic and international fuel supplies using a battery of test methods. This information would be used in estimating the fuel performance in an industrial gas turbine. Fuel properties of key interest were sulfur content, boiling point distribution, chemical constituents, ash content, and smoke point.

The survey required fuel samples from both domestic and international sources. Samples of fuel were taken from multi-product pipelines, bulk terminals, on-site storage facilities, and vendor supplied stocks. The bulk of the testing techniques employed were based on standardized ASTM methodologies. The scope of testing was greatly expanded beyond the normal fuel qualifications employed for industrial fuel characterization.

Results showed confirmation of the US EPA's regulatory efforts to reduce fuel sulfur levels to less than 0.05 wt%. However, there was not a significant difference between the sulfur levels of the higher grades of No. 1 type fuels (kerosine blends) and that of the more widely available No. 2 grade distillates.

The No. 2 grade distillates available in the US also showed a higher aromatics content than equivalent grades selected from international sources. This appears to be due to refinery processes in the US that are designed to optimize the gasoline yield from the refinery, resulting in higher aromatics content in some distillate streams.

INTRODUCTION

An industrial fuel survey was undertaken to understand potential changes in the quality of fuels available in the commercial markets. Of specific interest were fuel properties that might result in less than ideal performance when used in industrial gas turbine applications.

Historically, gas turbines have been well known for the ability to effectively use fuels of wide ranging characteristics and properties. Where reciprocating engines are impacted by the ignition quality of the fuel, or require a specific vapor pressure to burn, gas turbines do not typically exhibit sensitivity to fuel ignition properties. From an operating point of view, as long as the fuel can reach the fuel nozzle, and atomize properly, the only significant characteristic of concern is the presence of metals. Metals in the fuel, particularly alkaline and alkaline-earth elements are especially aggressive in their attack of hot metal surfaces. Therefore the metals content is often very tightly specified and controlled.

Advance turbines designed for low NO_x emissions have unique fuel hardware designs. Conventional designs consist of a pressure atomizing orifice type nozzle. The design is very forgiving, as well as easily manufactured and easy to repair. However, stricter environmental requirements have forced fuel system designers to develop improved atomization and mixing to reduce emissions, with an emphasis on NO_x. In some cases, the newer designs may impose more stringent requirements on the fuel. Determining a relationship between fuel properties and a system design was one of the long term goals.

METHODS

Standard ASTM[1] test methods were used extensively to evaluate fuel properties for this test program. No new methods were developed specifically to support these efforts. Other techniques which were also used include GC analysis of the fuel hydrocarbon structures.

Fuel samples were collected from various sources, placed in teflon bottles, and then shipped by overnight courier to the laboratories for analysis. Sample chemical analysis was usually completed within seven days after collection.

RESULTS

The test results are summarized by fuel grade (or type). In general, there were three grades of fuels identified:

1) No. 1/Jet A/Kerosene, but not including JP-5 grades
2) No. 2 distillate (including No. 2 fuel oil and diesel oils)
3) Gas-oils. Fuels similar to No. 2 based on ASTM classification, but with a wider distillation range, typically an endpoint that is greater than 700°F.

In addition, a reference highway No. 2 diesel fuel was used as a benchmark. This fuel sample was found to maintain relatively consistent analytical chemical properties from source-to-source, and from year-to-year.

The first comparison made is to summarize all of the fuels on a single chart, showing their boiling point range as a function of the percentage of the fuel distilled. From this chart, it is possible to clearly distinguish the specific grades of fuels just described. At the bottom of the chart lies a cluster for the No. 1 grade fuels. These are the kero-jet grades, widely available within the United States, but not the first fuel of choice for industrial applications because of the higher costs often associated with this transportation grade fuel.

The next cluster on the chart shows the No. 2 grade fuels. These fuels comply with the ASTM requirement that 90% of the fuel must be distilled at temperatures less than 640°F. In close proximity to the No. 2 grade fuels are the gas-oils, with a unique boiling point distribution. The gas-oils are identified primarily by the higher final boiling point which is exhibited on the right hand side of the figure.

Fuel Sulfur Analysis

Here in the United States, fuel is often hydro-treated to reduce the fuel sulfur levels. EPA requirements in the US have established diesel fuel sulfur maximums of 0.05 wt% (500 ppmw)[2], with gasoline sulfur requirements even lower. With declining feedstock quality, it is a requirement to upgrade the fuel using hydro-treatment, a process which lowers the product sulfur content. Table 1 summarizes the average sulfur levels encountered from fuel samples taken from both domestic and international sources.

Boiling Point

The data in Figure 1 show the clear delineation between the three types of fuels tested in this program. (Table 2 summarizes the endpoint analysis extracted from that data.) This figure shows that the end points on the gas-oils, samples collected from overseas sources, are distinctly different from comparable No. 2 grade fuels available in the United States.

Based on field test data, the effect of the higher end points for the gas-oil type fuels is expected to result in a higher smoke/particulate emissions than a lower boiling point fuel. A rule-of-thumb has been to require fuels with an end point that is less than 700°F in order to minimize the formation of a visible smoke plume, particularly at reduced loads.

Hydrocarbon Types

Hydrocarbon types were evaluated by two different methods: ASTM D 5291 and by chromatography. The general hydrocarbon classifications of interest are aromatics, olefins, and saturates determined using ASTM D 5291. The results of the analysis are summarized Table 3.

These are the results of 15 samples tested. The bulk of the US fuel samples exhibit saturates which are less than the average value shown in (70% for the average US values). All of the international fuel samples, with one exception, have higher saturate levels than the average shown in Table 3. A similar statement could be made for the aromatics, except that in this case, the lower aromatics tend to be clustered with the international fuel types (and the Jet A kerosines), while the higher aromatics are centered among the domestic grades of fuel (28.5%).

This appears to be consistent with the processing technologies associated with US refineries, and the limitations on aromatic hydrocarbons in the gasoline pool. Here in the US feedstocks are extensively upgraded to increase gasoline yields. This results in blending with Light Cycle Oil at the refinery that can produce very high concentrations of aromatics in the distillate streams. In addition, there are limits on the maximum aromatics content in the gasoline streams This requires that the excess aromatic components be re-distributed, and the distillate stocks targeted for stationary applications is the most convenient outlet.

For highway diesel and aviation kerosine applications aromatics more tightly controlled maintain cetane levels (for diesel fuels) and to meet aromatic specifications (for aviation applications). However, in the distillate heating oil market, there is no specific aromatic or cetane requirement for these fuels. Thus there would be a tendency to let the higher aromatic contents collect in this refinery stream.

In overseas markets there is still continued use of straight run distillates in large quantities. Also, Cetane improvers are not as widely used outside the United States. So the refinery stream for the distillates reflects a higher saturates and lower aromatics content than in the US.

Chromatography was used to further distinguish the chemical constituents that make up the fuel products. These are summarized in Figure 2. These results also show that the international grades clearly show lower aromatics, and higher paraffinic content that domestic US blends. Also, a high grade No. 2 highway diesel fuel is shown on the chart.

Ash Content

As expected, all samples tested showed ash contents that were reported at levels at or near the detection limits. The detection limits for ash using ASTM D 482 is reported to be 0.001 wt%; however, lower levels of detection are possible by using larger fuel sample volumes. In this program this was done to achieve the minimum detection levels reasonably achievable. The industry average of all fuel samples is 0.0015 wt% (15 ppmw). The significance of accurate ash measurement will be discussed in the next section.

Property Comparison: No. 1 and No. 2 Grades

Other relevant fuel properties were determined in addition to those described in previous section. A summary of those results is provided in Table 4.

DISCUSSION

The results show that US blends of both No. 1 and No. 2 fuels with sulfur levels consistent with the mandated US EPA requirements of 0.05 wt% maximum. While the average value shown in the table is slightly higher than that required by the EPA, the mean value is substantially influenced by a single sample which has a fuel sulfur level of 0.155 wt%. Removing this sample from the database lowers the average value to less than 0.043 wt%, meeting the US EPA requirements for fuel sulfur.

No. 1 Fuel

Results of the No. 1 fuel survey show excellent low sulfur characteristics. However, these fuels are substantially Jet A grade fuels (API gravity greater than 37 and 90% point is less than 540°F). Interestingly the No. 1 fuels show a broader boiling point range (exhibit a higher standard deviation) than the domestic No. 2 fuels. This is of virtually no impact with regard to fuel performance, although initial expectations were that the No. 2 fuel would likely exhibit the greater dispersion of the two fuel types.

International Fuel Grades

There is a clear trend toward the use of wider boiling point fuels in markets outside the United States and Canada. This was first observed by the author from fuel survey's conducted in Europe in the early 1990's. Higher end points were frequently found for distillate oils sold into the industrial/consumer markets. These fuels often did not meet the specific requirements established by the ASTM for No. 2 grade fuel (ASTM D396, D2880 or D375). The general performance of these fuels is expected to be similar to those of No. 2 grade fuels. However, there are some distinct differences to be expected. One of the most evident would be the production of a visible smoke plume. This phenomena has been associated with the liquid fuels exhibiting an endpoint that is 700°F or higher. This endpoint is reached or exceeded for most fuels similar to No. 2 distillate that are available in the international markets (Europe, Asia, South America).

In Germany, two grades of this fuel are available for general consumption. They are classified as IGO (Industrial Gas Oil) and AGO (Automotive Gas Oil). The AGO cut exhibits a lower endpoint, and less smoking tendency, than the IGO product. The features associated with AGO (reduced final boiling point) produce a less visible exhaust plume when burned in power applications.

ENVIRONMENTAL IMPACT

Certain fuel properties clearly affect their environmental performance. Fuel bound sulfur and nitrogen are the two of the most important. However, test results in this program have shown that both the domestic and international fuels exhibit very low sulfur levels, and would produce SO_2 emissions that would be difficult to measure during exhaust emission testing.

Not so clear is the impact of other fuel qualities, such as aromatics content, smoke point, and ash. These specific fuel properties, as well as others, can impact the formation of smoke, particulates, and a visible plume. Distinguishing particulates between carbon/organic and inorganic (or ash) components is difficult to predict. However the inorganic ash component is the easiest of the two to estimate. The laboratory results from ASTM D 482 are assumed to represent the same ash constituents that would be released into the environment. For a large industrial gas turbine, using 100,000 lb/hr of liquid fuel consumption, a test analysis with detection limits of 0.01 wt% would produce an expected particulate emission rate of 10 lb/hr (0.0077 lb/MMBtu, HHV basis), based solely on the ash constituents. There is no straightforward mechanism for estimating the additional particulates due to the carbon/organic fraction. But evidence from field tests clear shows that fuels with final boiling points in excess of 700°F can, under the proper set of conditions, produce a visible plume.

Based on the test results from this program, using the same conditions just described would result in particulate emissions due to the ash content of the fuel at approximately 1.5 lb/hr (0.00077 lb/MMBtu, HHV basis). This level of particulates would produce no visible plume, and would be extremely difficult to measure using standardized test methods.

CONCLUSION

Fuel sulfur levels within the United States reflect the impact of federal legislation mandating sulfur reductions to less than 0.05 wt% (500 ppmw). Only in one instance was a fuel for gas turbine applications identified with a sulfur content greater than this.

US fuels are substantially dominated by higher aromatics and lower saturate contents than comparable non-domestic grades of fuels (excluding the Jet A kerosine grades). The higher aromatic contents may result in greater particulate emission, or possibly a visible smoke plume. International samples show trends of higher saturates and lower aromatics, somewhat similar to the general hydrocarbon information identified for Jet A grades of fuel.

Ash contents of all fuel samples tested were very close to the detection limits of the test method. An average value of 15 ppmw was reported.

These results, as well as additional test parameters being considered, will eventually be used to develop more useful and effective fuel specifications for industrial gas turbine applications.

ACKNOWLEDGMENTS

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REFERENCES

[1] ASTM 100 Barr Harbor Drive, West Conshohocken, Pa. 19428

[2] US EPA 40 CFR 80.29. Beginning 1 Oct 93 sulfur is limited to 0.05 wt% for highway diesel.

[3] "A Comparison of Low and High Sulfur Middle Distillate Fuels in the United States", J. Andrew Waynick, 215th ACS National Meeting, Dallas, TX. March 29, 1998

Table 1 Measured Fuel Sulfur Levels (ASTM D4294)

Fuel Type	Average	Minimum	Maximum	Standard Deviation
No. 1	0.0207	0.003	0.0322	0.0119
No. 2	0.0535	0.025	0.155	0.035
Amoco Fuel Analysis (1994)[3]				
Low Sulfur Diesel	0.0296			0.0092
High Sulfur Diesel	0.2082			0.0902

Table 2 Boiling point distribution

	End Point		50% Point		90% Point	
	Average, °F	SD	Average, °F	SD	Average, °F	SD
No. 1	540.8	17.1	424.7	12.8	493.4	15.8
No. 2	657.1	7.8	511.4	11.7	607.6	7.3
Gas Oil	693.6	23.5	538.9	8.7	647.9	21.4

Table 3. Fuel classification by hydrocarbon types (ASTM D 5291)

	Hydrocarbon Analysis by Volume % (All Fuels Tested)			
	Olefins	Aromatics	Saturates	Smoke Point
Average	1.13	23.06	75.80	18
Standard Deviation	0.472	6.982	7.127	3.0
Maximum	2.3	35.8	84.92	23
Minimum	0.39	14.2	62.4	12

Table 4 General fuel properties

	No. 1/Kerosene	No. 2 Distillates
Flash Point, °F	144	160
Pour Point, °F	-59	-8
Kinematic Viscosity @ 104°F (cSt)	2.08	3.03
Specific Gravity	0.82	0.854
LHV, Btu/lb	18,526	18,327
HHV, Btu/lb	19,747	19,446
Carbon Content, wt%	86.22	86.71
Hydrogen Content, wt%	13.57	13.05
Oxygen Content, wt%	0.16	0.13
Nitrogen Content, wt%	0.0078	0.018
Sulfur Content, wt%	0.0322	0.0535

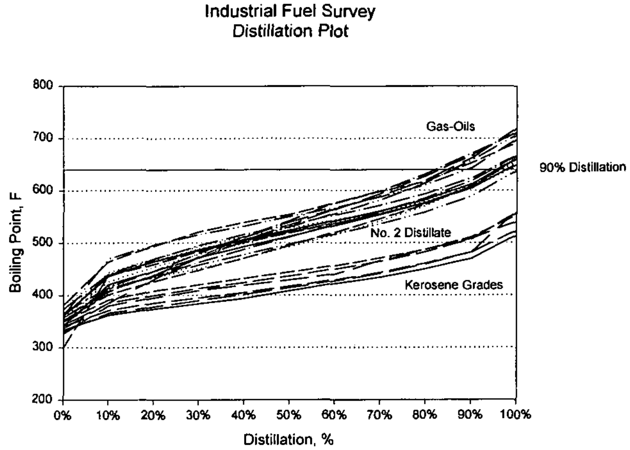

Figure 1. - Boiling Point Distribution for Three Fuel Grades

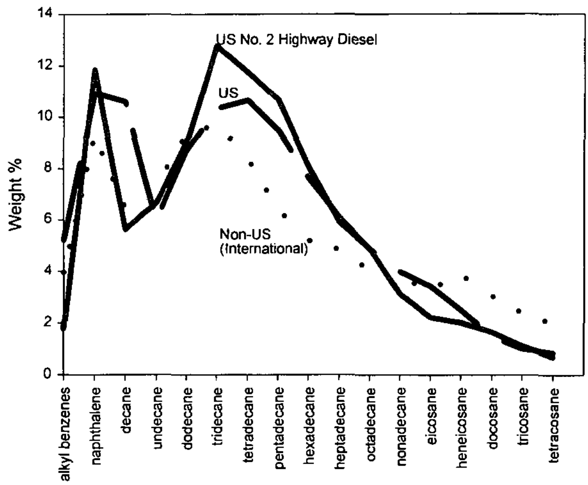

Figure 2. - Fuel Chromatography Analysis.